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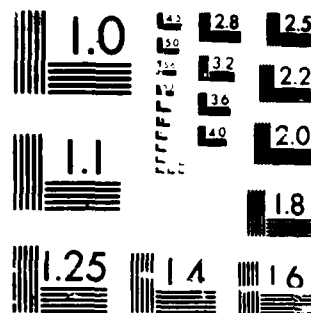DAJA45-86-M-0493

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Plate impact experiments were performed on two grades of oxynitride glass, supplied by Dr. D. Messier, AMTL, Watertown. Material manganin guages were used to determine the dynamic response of this material in the range of 0 to 12 GPa. In the high stress range the measured stress signals showed that the transmitted waves are composed of an initial elastic jump followed by stress relaxation and a subsequent "plastic" wave. The "plastic" transition occured at 7.0±0.2 GPa for a 6.0 at % nitrogen glass and at 10.4±0.3 GPa for a 3.3 at % nitrogen glass. This behaviour is characteristic of ductile metals, but is seldom observed in glasses. The Hugoniot curves for both the above nitrogen compositions were dtermined in the range of 0 to 1 GPa and their spall strength in this pressure regime was estimated from the manganin guage record.

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The Dynamic Response of

Oxynitride Glass

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ABSTRACT

Plate impact experiments were performed on two grades of oxynitride glass supplied by Dr. D. Messier, A.M.T.L., Watertown. In-material manganin gauges were used to determine the dynamic response of this material in the range 0 to 12 GPa. In the high stress range the measured stress signals showed that the transmitted waves are composed of an initial elastic jump followed by stress relaxation and a subsequent "plastic" wave. The "plastic" transition occured at 9.0 ± 0.2 GPa for a 6.0 at.% nitrogen glass and at 10.4 ± 0.3 GPa for a 13.3 at.% nitrogen glass. This behaviour is characteristic of ductile metals, but is seldom observed in glasses. The Hugoniot curves for both the above nitrogen compositions were determined in the range 0 to 12 GPa and their spall strength in this pressure regime was estimated from the manganin gauge record.

-1-

1 INTRODUCTION

The dynamic response of brittle solids to impulsive loading has been the subject of many publications over the past twenty years. The review article by Davison and Graham[1] discusses many of the important issues in stress wave propagation for these materials. It would appear that a single, comprehensive model which could account for all the observed features of impact behaviour is still lacking.

The recent work of Kamel et al.[2] on soda-lime glass and our own results on borosilicate glass[3] have shown that for shock stresses exceeding the Hugoniot Elastic Limit (HEL) the spall strength is reduced to almost zero. This is in contrast to the more familiar spall signal which is observed in most metals.

This report presents preliminary experimental results on the dynamic behaviour of two oxynitride glasses supplied by D. Messier (AMTL). The Hugoniot curves of both glasses were measured and the glass of higher nitrogen content was found to give the higher Hugoniot slope for the elastic portion of the curve. Below the HEL the spall strength of the two glasses was very similar and spalling was found to occur at the impact pressure. The spall strength decreased to almost zero with increasing shock pressure above the HEL.

-2-

2 EXPERIMENTAL METHOD

2.1 GUN DESCRIPTION

The planar impact experiments were conducted in the 2.5 and 4.0 inch gas guns described elsewhere[4,5]. Impact velocities were measured to an accuracy of $\pm 0.5\%$ and ranged between 100 and 700 $m.s^{-1}$, which corresponded to stresses in the range 2.5 to 12.0 GPa for a copper impactor.

The manganin gauges (M.M. type LM-SS-125cH sp60) were previuosly calibrated under both loading and unloading conditions[6,7]. The above references also describe details of gauge emplacement and data reduction proceedures. The gauges are grid-like foils 0.5 um thick deposited on 0.04 mm epoxy sheet. The gauges were either glued between two plates of lapped oxynitride glass, as shown in fig. 1, or between a single glass disk and a poly(methyl-methacrylate) (PMMA) backing plate, as shown in fig. 2a. In the first configuration, designated "in-material", we obtain points on the Hugoniot curve, and from the second, "back-surface", configuration we are able to evaluate the spall-strength and the HEL of the specimens.

The basic principles involved in measuring the spall strength of shock-loaded specimens using manganin gauges were described previously[8] and possible effects are shown schematically in fig.2b. This figure illustrates the expected behaviour for a zero spall strength, for finite spall strength and for no spalling.

2.2 MATERIAL SPECIFICATIONS

Two types of oxynitride glass disks designated "a" and "b" were supplied by D. Messier. The disks were cut and lapped to achieve planarity. The compositions have been published and the major difference is in the nitrogen content[9].

Elastic modulus and longitudinal sound velocity were characterised by ultrasonic measurements. For type "a" glass the follwing data were obtained:

Elastic modulus (E)	145 GPa
Shear modulus (G)	56 GPa
Poisson's ratio (υ)	0.29
Logitudinal sound velocity (C_L)	6.9km s^{-1}
Density (ρ)	3.74 gm. cm.$^{-3}$

3 RESULTS AND DISCUSSION

3.1 THE HUGONIOT CURVES

As noted above, the Hugoniot curves were primarily determined using the "in-material" gauge configuration (fig. 1). The final stress level, as determined from the gauge calibration curve[6] and the measured impact velocity, gives a single point on the stress-particle velocity Hugoniot of the oxynitride glass. Copper impactors were mainly used, since accurate Hugoniot data for copper are available in the literature and it's impedance (density X longitudinal sound velocity) is well matched to that of the oxynitride glass. In the future we would like to improve the accuracy by performing symmetrical impact experiments in which the impactor is made from the same oxynitride glass as the specimen. The experimental Hugoniot

curves are shown in fig.3. These data also include a few of the
data points estimated using the "back-surface" specimen configuration.
As can be seen from the figure, the higher nitrogen content glass
gives a significantly higher Hugoniot slope. This is in agreement
with the higher elastic modulus of this material. The reduction in
slope of the Hugoniot above the respective HEL values of the two
materials is also clearly evident.

The accuracy of the stress measurements in fig.3, as determined
from the gauge calibration curves[6], is $\pm 2\%$. The error in stress
measurement is in effect larger than the error associated with the
Hugoniot curve assymmetry arising from the dissimilar impactor and
target materials.   In   the "back-surface" configuration with
assymmetrical impacts the error in Hugoniot stress determination is
greater and is estimated to be about +5%. In order to reduce this
error more specimens would be required for additional symmetric
experiments in the "in-material" configuration.

The elastic limit of the Hugoniot curve (HEL) was determined from
the "back-surface" configuration (fig.2a). This configuration also
permits an estimate of the spall strength to be made. A typical gauge
record is shown in fig.4. The stress jump to the elastic limit is
clearly visible, followed by strong elastic stress relaxation and a
slower, "plastic" wave. In fig.5 a gauge record is given for the
"in-material" configuration at a stress level below the HEL. In this
case the initial stress jump is completely elastic.

The shock velocity is determined from the difference in transit times through the specimen disk between the elastic and plastic waves. For the type "a" glass the calculated shock velocity was 5.3 ± 0.2 $km.s^{-1}$, which is in excellent agreement with the value of 5.2 $km.s^{-1}$ calculated from the ultrasonic measurements and the elastic moduli K and G using the relations:

$$K+4G/3 = \rho C^2$$

$$C = \sqrt{K/\rho}$$

The HEL is determined from the accoustic impedance of the glass (Z_1) and PMMA (Z_2) in the relation:

$$\sigma_{HEL} = (Z_1+Z_2)/2Z_2 \cdot \sigma_E$$

where σ_E is the measured elastic jump in the stress signal transmitted to the PMMA backing plate in the "back-surface" configuration. This relation gave values of HEL for types "a" and "b" glass of 9.0 ± 0.4 GPa and 10.4 ± 0.4 GPa respectively. These values are much higher than those reported for soda-lime glass[10] (6.4 GPa). The dynamic yield stress can be estimated from the HEL using the relation:

$$\sigma_Y = (1-2\upsilon)/(1-\upsilon) \cdot \sigma_{HEL}$$

For the type "a" glass we obtain a value of 5.3 GPa for the dynamic yield strength under uniaxial stress. The dynamic yield strength of most FCC metals is approximately equal to the static compressive strength. Compressive strength data on the oxynitride glasses would enable this comparison to be made.

3.2 THE SPALL STRENGTH

The "back-surface" configuration shown in fig.2 can be used to determine the spall strength, since when free surface is generated inside the target during spallation part of the relief wave reverberates between this surface and the specimen/PMMA interface. These reverberations are recorded by the manganin gauge at the interface and the spall strength is calculated from the amplitude of the reverberations. A similar approach has been used by John n on copper. The spall strength is estimated from the relation:

$$\sigma_{spall} = (z_1 + z_2) . 2z_2 . \Delta\sigma$$

where $\Delta\sigma = \sigma_2 - \sigma_1$ is the difference between the maximum and minimum spall rebound signals as illustrated in fig.6

From the value of $\Delta\sigma$ we can compute the spall strength by assuming that the Hugoniot curves are linear in the region of interest and using the manganin gauge calibration curve[6].

For impact stresses below the HEL the spall signal reverberation resembles that for a metal such as copper. There was no significant difference in the spall strengths of the two glasses, which decreased from 0.8 ± 0.2 GPa to zero as the impact stress increased from 2 GPa to the HEL. This is higher than has been reported previously for alumina or other ceramic armour materials. For example AD-85 grade alumina was found to have a maximum spall strength of 0.3 GPa [12].

The decrease of the spall strength to zero above the HEL indicates that the material has disintegrated at this point. This was also the conclusion of Munson and Lawrence [13] who recorded a negligible spall strength for Lucalox samples shocked to above the HEL.

4 CONCLUSIONS

The shock wave characteristics of oxynitride glasses have been determined using manganin gauges in both the "in-material" and the "back-surface" configuration to yield information on the state of the materials under both loading and unloading conditions. In particular the Hugoniot elastic limit (HEL) was found to be very high (9 to 10 GPa) with a high Hugoniot slope. The spall strength was also found to be higher than in most ceramic armour materials. Errors in the present results were attributed mainly to material variability from one sample to another. More accurate measurments will require additional experiments in order to improve the data statistics

An additional feature was also observed in the stress signal from the oxynitride glasses which showed that the elastic wave was followed by stress relaxation and a "plastic" wave. More work will be required in order to understand this behaviour. Although the observed spall strength was higher than that of many brittle ceramics it was still lower than that measured for commercial soda-lime glass. Complete characterisation of these materials will require more experiments in order to resolve the stress relaxation behaviour and to improve the accuracy of the Hugoniot curve by the addition of more experimental points, especially in the range above the HEL.

-8-

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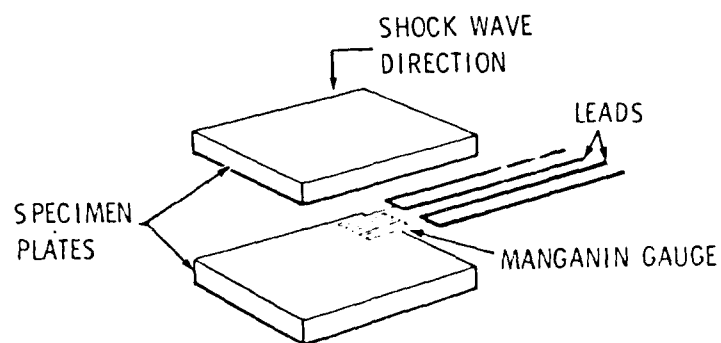
Fig.1   "In-material" manganin gauge embedded between two glass tiles
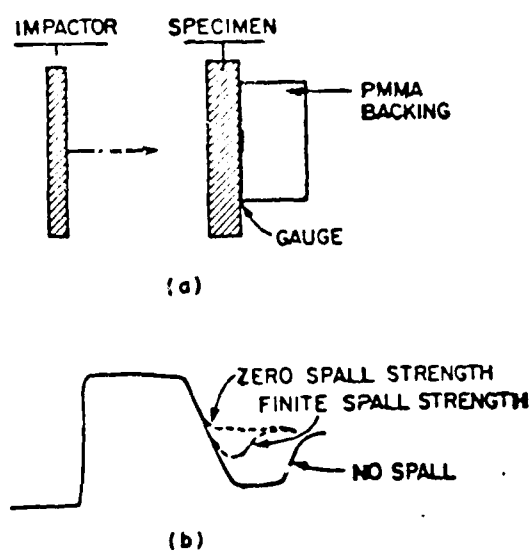

(a)

(b)

Fig.2   "Back-surface" configuration:

(a) Experimental set-up.

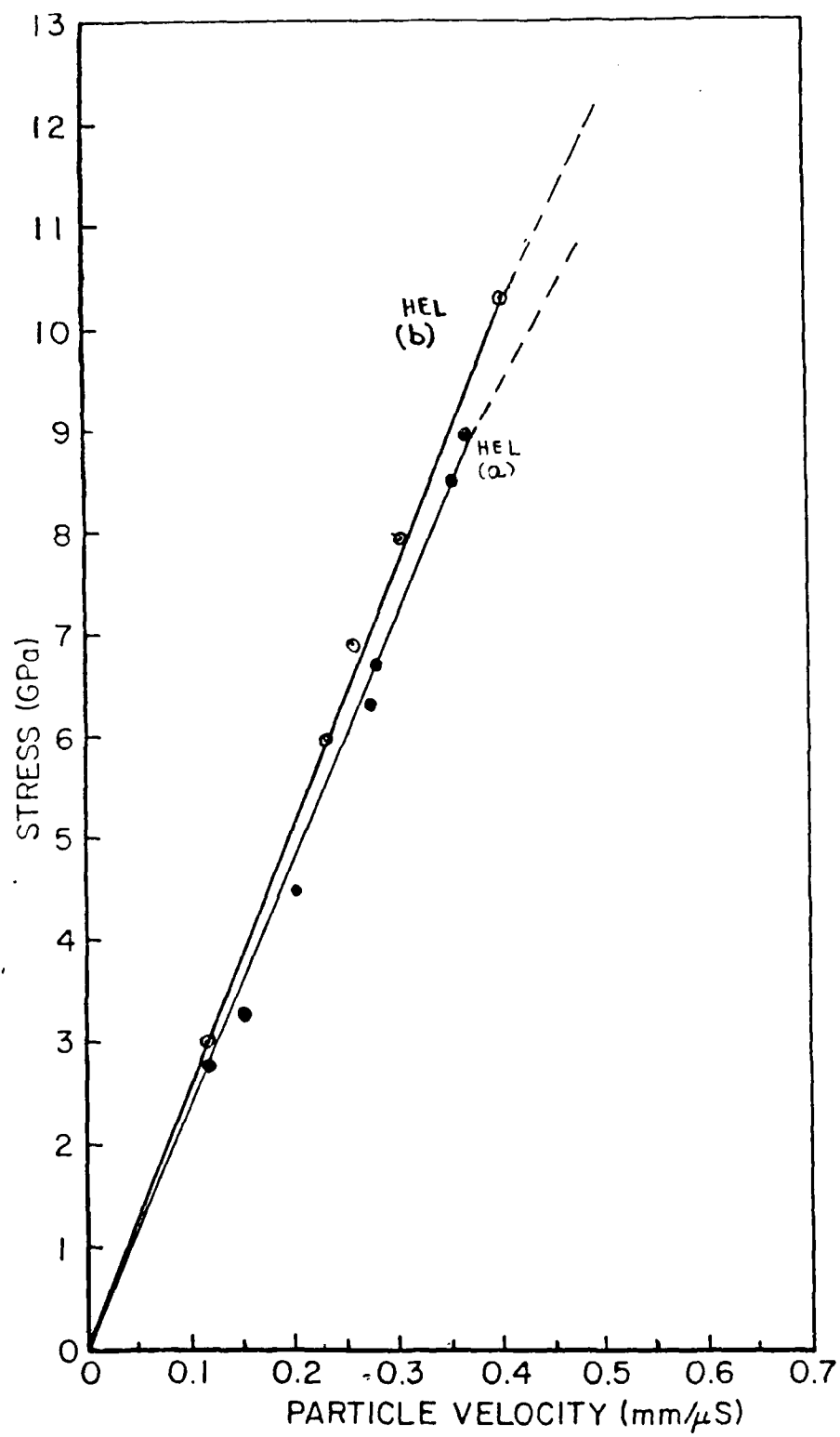(b) Schematic of gauge record showing effect of spalling.

Fig.3 Measured Hugoniot curves and experimental points for types "a" and "b" oxynitride glasses.

Fig.4   Typical gauge record for the "back-surface" configuration above the HEL.

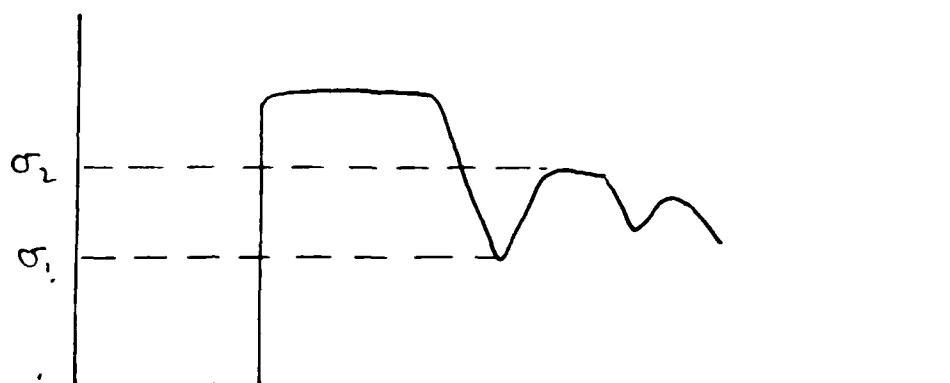Fig.5   Typical gauge record for the "in-material" configuration below the HEL.

Fig.6   Schematic illustration of spall rebound signal.

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